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Development of University Life-Science Programs and University-Industry Joint Research in Japan

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Abstract

How does the establishment of new university educational programs promote university-industry joint research? To study this question for the fields of life sciences and biotechnology, we first compile the data on the establishment of new undergraduate and graduate programs in these fields in Japanese universities since the 1950s. We then analyze statistically whether and how such establishment contributed to the occurrence and frequency of university-industry joint research in biotechnology. The results suggest that, first, the expansion of such university programs in fact contributed to the promotion of university-industry joint research and, second, these collaborations increased following the 1998 legislation to promote technology transfer from universities (the so-called TLO Act) and the 1999 legislation to allow universities to retain rights on their inventions made with government research funds (the so-called Japanese Bayh-Dole Act).

1. Introduction

The role of universities in the advancement of new industries is now widely recognized. Historically, universities contributed to industrial innovation not only by supplying educated scientists and engineers but also by advising industries, helping them to learn new technologies, and performing joint research with them: see Rosenberg and Nelson (1994) and Mowery et al. (2004) for the US; Murmann (2003) for Germany; and Odagiri and Goto (1996) and Odagiri (1999) for Japan. This trend has accelerated in recent years and, now, university-industry collaborations (hereafter UI collaborations) are actively pursued in every developed country in a variety of ways both formally through UI research contracts, university licensing, and other contracts, and less formally through consulting and miscellaneous informal UI interaction. Many survey studies testify to this fact. In the US, when asked about the importance to industrial R&D of various information sources related to public research, 36 percent of the respondents replied that “informal interaction” is at least modestly important, 32 percent replied the same for “consulting”, and 21 percent for “contract research” (Cohen et al., 2002). This result suggests that many firms are benefitting from UI collaborations, in addition to open-source academic research such as publications and reports, for which 41 percent of the respondents replied similarly. In Japan, 24 percent of large-scale companies (with 250 employees or more) with innovative activities replied that they cooperated with universities for innovations and 56 percent of them replied that universities are highly or moderately important partners for cooperation (Ijichi and Odagiri, 2006). In Europe, similar evidences are given in community innovation surveys (CIS); for instance, in Belgium, 27 percent of firms that innovated had a cooperative agreement with universities (Veugelers and Cassiman, 2005).

Nowhere is such UI collaboration more important than in the field of biotechnology and health care, most notably pharmaceuticals. In the same US survey, more than a half, namely 53 percent, of pharmaceutical firms replied that contract research is important, far exceeding the percentage for all industries (21 percent). In Japan, 70 percent of firms in the pharmaceutical industry replied that they had cooperated with universities for innovation, again far exceeding the figure for all industries (24 percent). This closeness of university research and industrial application in pharmaceuticals owes mainly to two factors. The first is the intrinsic nature of the industry. From the beginning of the modern drug industry and the chemical industry in the latter half of nineteenth century in Germany, the most advanced country at the time, the interaction between universities and industries played significant roles (Murmann, 2003). Today, ‘science linkage’ as measured by the frequency of citation to scientific papers in patent applications is known to be particularly prominent in the biotechnology and pharmaceutical fields (McMillan et al., 2000).

The second factor for the importance of UI collaboration in biotechnology is the rapid progress of related basic sciences, mainly life sciences. As exemplified by the discovery of DNA double helix structure by J. D. Watson and F. H. C. Crick in 1953, the invention of genetic engineering technique by S. Cohen and J. Boyer in 1973, and the completion of the International Human Genome Project in 2003, the latter half of the twentieth century saw a historically unprecedented speed of development in life sciences, which could be applied to industrial innovation. The consequence was that the businesses had to follow scientific development closely so as not to be left behind competitors. University researchers also needed close collaboration with industries to prove industrial applicability of their research results.

The close UI relationships and active collaborative activities common in biotechnology-related industries, such as pharmaceuticals and agriculture, have been documented and studied by many (e.g., Henderson et al., 1999, Pisano, 2002, McKelvey et al., 2004, and the papers in McKelvey and Orsenigo, 2006). That the extent and manner of UI collaborations are dependent on the national innovation system characterized by the legal system, the business system, the labor system, the university and other educational systems, government policies, and such has been also noted: see Nelson (1993) for an international comparison of national innovation systems and Kneller (2007) for a Japan-US comparison in relation to biotechnology and pharmaceuticals.

Another important fact is that, even though scientific community has become global in the sense that published research results can be accessed worldwide virtually without delay, geographical proximity still plays an important role in UI collaborations. Owen-Smith and Powell (2004) studied the biotechnology knowledge network of the Boston area and found that ties with local research community increase biotech firms’ patents. Zucker et al. (1998) found a positive influence of the presence of star researchers and top-quality universities in the region on the birth of biotech firms in the US while Zucker and Darby (2001) found that linkages with local star scientists contributes to product development of Japanese biotech firms. Geographical proximity is important because face-to-face communication makes UI collaborations effective. Faculty members may visit firms’ laboratories to give advices or company researchers may visit university laboratories to perform joint research with faculty members and receive advices from them. Even with the advancement of the internet, intimate collaborations require frequent face-to-face communication and joint research at the spot. Just like the well-known fact that, in machinery production, the participation of both engineers and plant workers is essential for continuous productivity improvement, UI joint research requires continuous collaborations between academic and industry scientists.

This fact implies that the presence of academic institutions in close proximity to firms, in terms both of geography and of research theme, is a prerequisite for these firms to undertake UI joint research and benefit from the universities’ knowledge and research capabilities. This proposition will be theoretically analyzed and the implications discussed in Section 2. One important consequence is that, for UI joint research to be carried out smoothly and fruitfully, the country must have universities with educational and research facilities in related fields. The development of university educational and research programs in life sciences and biotechnology will encourage the faculty to carry out collaborations with firms aiming at industrial application of biotechnology.

With this view in mind, we will investigate in this paper, first, how such educational programs developed in Japan in the last few decades and, second, how this development contributed to UI joint research. The structure of the paper is as follows. After a theoretical exposition in Section 2, we will give in Section 3 an account of the development of UI collaborations in Japan and important policy changes since the latter half of the 1990s. In Section 4, we will collect the data on the expansion of university educational programs (schools and departments at undergraduate and graduate levels) in the fields of life sciences and biotechnology in Japan and show that such expansion took place actively since 1985. In Section 5, after explaining the data on biotechnology-related joint research contracts of Japanese national universities with industries during 1995-2000, we will explain our empirical methodology as well as the testable hypotheses derived from the theoretical predictions of Section 2. In Section 6, the results of university-year panel regressions using the two sets of data – one on university programs and the other on UI joint research – will be presented. They support our main hypothesis that the establishment of university life-science educational programs promotes UI joint research in biotechnology. In addition, the regression results imply that the policies taken in Japan to foster UI collaborations had the intended effect. Section 7 summarizes these results and discusses their implications.

2. University Programs and Joint Research – A Model

Establishing a new university program on life science will result in more active UI joint research activities, since firms will then have a bigger chance of finding suitable research partners. This proposition can be demonstrated by means of a spatial differentiation model *a la* Hotelling (1929).

We consider a spectrum of research themes that are distributed along a line[1] and assume that life-science educational and research programs of different university can be characterized by different locations (ℓ); for instance, University *j* is located at ℓ_j and University *j*+1, at ℓ_{j+1}. Location here may be understood as geographical

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[1] Hotelling assumed that players (consumers, firms, and such) are located along a straight line that has ends in both sides. We ignore the presence of such ends because, very likely, there is no end in the distribution of themes, unlike in tastes – from hot to cool, or radical to conservative – or politics – from right-wing to left-wing. In this regard, the model is more akin to the circular model of Salop's (1979).

location because, as discussed above, geographical proximity between a firm and a university will make their joint research easier. However, given Japan's relative small size and denseness, proximity in research themes is probably a more important determinant of joint research. We will thus think of location in regard to research themes and assume that universities have advantages in different themes; for example, University *j* may be known for its stem-cell research while University *j+1* may be known for protein research, which is why, in Figure 1, their locations, ℓ_j and ℓ_{j+1}, are separate along the line. We are aware that it is a gross simplification to place different research themes along a uni-dimensional line and represent the research theme of each university's comparative advantage by a single point on this line. Nevertheless, we believe the model is not a far-fetched depiction of real firms' choice of joint research partners and is useful for expositional purposes and for the purpose of deriving testable hypotheses.

Consider a firm that is seeking an opportunity to conduct a joint research project with a university that preferably has knowledge and capability on research theme depicted by location ℓ. If there is a university *j* that is located exactly at this point (i.e., $\ell_j = \ell$), the firm will of course choose University *j* as the partner and the expected return (in present value) from this collaboration will be denoted by V_j. V_j may differ across universities because of their different research capabilities.

It is seldom, however, that the firm can find a university that perfectly fits its desired research theme. Usually, there is a distance, measured by $|\ell - \ell_j|$, between its desired theme and that of University *j*. Because the expected return from joint research will be lower the larger the distance, we can write the return as $V_j - t|\ell - \ell_j|$, where *t* denotes per-distance decline in the expected return[2]. This expected return is shown in Figure 1 by the straight lines sloping downward to both sides from the height of V_j at location ℓ_j. Given the cost (in present value) of joint research at *C*, the firm will undertake joint research with University *j* if and only if $V_j - t|\ell - \ell_j| > C$. Therefore, if $C = C^1$, firms located between $\bar{\ell}^1_{j-}$ and $\bar{\ell}^1_{j+}$ in Figure 1 will undertake joint research with University *j*.

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[2] Needless to say, in the usual location theory, *t* is the per-meter (or per-mile) transportation cost.

This model, despite its simplicity, gives a few useful predictions. First, the establishment of a life science program with a research theme distinct from those in other universities will provide new opportunities for firms that hitherto have not participated in any UI joint research. Were it not for the presence of University *j* at ℓ_j, those firms located between $\overline{\ell}^1_{j-}$ and $\overline{\ell}^1_{j+}$ would not have undertaken any UI joint research. Since $\ell < \overline{\ell}^1_{(j+1)-}$, these firms will not undertake joint research with University *j+1* either. Neither will they undertake one with University *j-1* and so forth. Hence, only with the establishment of University *j*'s program will they begin a UI joint research activity.

Second, the establishment of a new life science program may also encourage firms to increase the number of joint research projects they perform with universities. Suppose that the cost of joint research is lower at C^2. Then, as is apparent from Figure 1, those firms between $\overline{\ell}^2_{(j+1)-}$ and $\overline{\ell}^2_{j+}$ will undertake two joint research projects, one with University *j* and the other with University *j+1*. For these firms, the establishment of University *j*'s life-science program means an opportunity to increase and diversify the portfolio of their joint research projects.

Third, a higher V_j will lead to a higher likelihood that the university has one or more joint research contract with firms, because it becomes more likely that there are firms satisfying $V_j - t\left|\ell - \ell_j\right| > C$. Also, it will result in more firms partnering with University *j*. Hence, if, for instance, V_j increases over time as the university gradually builds reputation by hiring new faculties, attracting better graduate students, and accumulating capabilities for scientific experiments and tests, then, more firms will find the university to be a more attractive research partner.

These theoretical predictions will be formalized as testable hypotheses in Section 5 and empirically tested in Section 6. We believe that, despite its simplicity and its straightforward extension from the spatial differentiation model, the model will provide a useful framework for analyzing these and other likely consequences of the establishment and location (both in terms of geographical location and research themes) of universities.

3. University-Industry Collaborations and Policy Changes in Japan

In the mid to late nineteenth century when Japan’s modern economy took off, universities played important roles in Japan's industrial and technological development. As was somewhat common with the US, another late-developing country at the time, Japan was desperate to catch up with the advanced technologies of European nations. Thus, its higher education system emphasized the acquisition of practical technological knowledge and skills. Technologically knowledgeable people were scarce and mostly in universities; hence, industries actively sought information and advice from university faculties. In electrical equipment, pharmaceuticals, and other industries, university faculties helped the start of today’s leading firms by, for example, giving advices, becoming chief technology officers, and starting new enterprises (Odagiri and Goto, 1996).

Unfortunately, a uniform and rigid regulation began to be applied to the conduct of university faculties and this tendency became apparent with the post-World War II university reform that emphasized uniformity than flexibility (Hashimoto, 1999). Such regulation was strictly enforced because most of the major universities in Japan were national and their professors were civil servants[3]. For instance, joint research with firms required tedious paperwork and, at times (for instance, during the Vietnam War and during the student movement in the late 1960s), met hostility from students. Professors were not encouraged to apply for patents and could not become a director of a private company. It is not that UI collaborations were absent. Actually, there were many cases of collaboration but they were mostly done informally (Odagiri, 1999). Often, firms seconded their researchers to university laboratories as graduate students or visiting faculties and donated research funds to professors instead of sharing research costs following formal UI joint research contracts. Professors often relegated the right to patent their inventions to donating firms instead of the universities or the professors applying for patents.

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[3] As will be shown in the next section, private universities overwhelm national ones in terms of the number of universities or of students; however, most major universities are national.

However, following the declaration of Science and Technology Basic Plan in 1996, the government took several policy initiatives to deregulate and encourage UI collaborations. For example, professors can now join boards of directors of private companies. Universities can now accept research funds more easily from industries and accept researchers dispatched from companies at university laboratories. Many universities have built special facilities for UI joint research. They can also offer their space to startups at a low rent, if these startups were established for the purpose of commercializing technologies of the university's origin. Also, companies can take advantages of special tax concession regarding their R&D expenditures spent for UI collaborations.

Two laws were particularly important – *Daigaku-tou Gijutsu Iten Sokushin Ho* (the Law for Promoting University-Industry Technology Transfer) enacted in 1998 and *Sangyo Katsuryoku Saisei Tokubetsu Sochi Ho* (the Industrial Revitalization Law) enacted in 1999. As the title of the law indicates, the first law purported to promote technology transfer from universities to industries. Accordingly, the government, with subsidies and other policy measures, encouraged universities to establish technology licensing offices (TLOs) that should help faculty members in applying for patents and licensing them and help companies in finding suitable university patents to be licensed and suitable faculties to start joint research with. The law is thus commonly called "the TLO Act".

The second law is usually called "the Japanese Bayh-Dole Act" because, like the US Bayh-Dole Act, it allowed the state not to acquire patent rights from those inventors making research with government funds. In the US, after the passing of the Bayh-Dole Act in 1980, patent applications by universities are known to have significantly increased[4]. Similarly, the number of university patent applications

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[4] Henderson et al. (1998) argued that most of the post Bayh-Dole increase in university patenting was caused by patent applications of less important inventions (as inferred by the frequency of citation) and/or by the entry of universities that were inactive applicants before the Act. Mowery et al. (2004) extended the study period to find that such tendency has become less apparent in the 1990s, suggesting that universities have learned from patenting experience and become more selective in

increased in Japan after 1999 and, together with the incorporation of national universities to be discussed below, the number jumped to 3,756 during 2004. Again similarly to the US, about a third of these applications are made in the field of life sciences and biotechnology.

Furthermore, in 2004, the National University Corporation Law was enacted, with which every national university in Japan was incorporated into a semi-independent corporation. Although the major part of these universities' budget continues to be supported by the government, the law promoted UI collaborations further for several reasons. First, incorporated universities themselves can now possess patents, whereas in the past university inventions belonged to the nation. Second, as the faculty members are no longer civil servants, more flexible employment arrangement became feasible, making it easier for faculties to work for companies part-time and receive industry funds. Also, universities can now offer customized employment conditions in order to recruit specialists with expertise on patenting, licensing, spinning-off, and other activities. Third, naturally, each university now has a greater incentive to increase its revenue not only by offering more up-to-date courses but also by attracting industry funds for UI collaborations and promoting patenting and licensing of university inventions.

With these reforms, UI collaborations have been increasing rapidly[5]. The number of UI joint research by national universities increased from 1139 in 1990 to 4029 in 2000 and 6767 in 2002. The number of new startups based on university-invented technologies increased from 11 in 1995 to 135 in 2002 and, in 2005, the accumulated number of such companies in operation was more than 1000. Though this figure is smaller than in the US, the increase is impressive[6]. 46 TLOs have been set up and several cases of licensing have been already reported, even if they are still few and

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their choice of inventions to be patented.

[5] The following statistics are available at the website of the Ministry of Education, Culture, Sports, Science and Technology (http://www.mext.go.jp/), although few of them are in English.

[6] In the US, 450 startups were formed in 2002 and the accumulated number during 1980-2002 was 4,320 of which 2,741 were still in operation. Source: The Association of University Technology Management, *AUTM Licensing Survey: FY2002*.

most TLOs are still suffering from loss.

One of the purposes of the present study is to estimate the impact of these policies on UI joint research in Japan by using micro data at the university level. Unfortunately, the data covers only the 1995-2000 period and we cannot examine the impact of the 2004 law with which the national universities were incorporated. Still, our finding that the number of UI joint research contracts in relation to biotechnology significantly increased after 1998 and 1999, respectively the years for the TLO Act and the Japanese Bayh-Dole Act, must indicate that the policies played expected roles.

4. Expansion of Life Science Education in Japanese Universities

Universities played a major role in the development of life sciences. In turn, the development of life sciences prompted universities to change. New research fields, such as molecular biology and bioinformatics, increased their importance, fostering universities to start new faculties and laboratories to study and teach these fields. Both academic and industrial demands increased for graduates with the knowledge on such new sciences and technologies, prompting universities to start new departments and graduate schools to teach these subjects. Put differently, were it not for swift reorganization of universities, neither academic research nor its industrial application can be expected to progress.

Let us take the case of Massachusetts Institute of Technology (MIT)[7]. In the 1950s, molecular biology became an important part of the Department of Biology and, in the 1960s, a center for life sciences was established within the department. In 1977, MIT established Whitaker College of Health Sciences and Technology, and the Harvard-MIT Division of Health Sciences and Technology was started as a joint program between Whitaker College and Harvard Medical School. These are interdisciplinary programs and many of the faculties held joint appointments with other departments, schools, programs, and laboratories. In addition to the usual

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[7] All the information and citation in this paragraph were taken from the websites of MIT and Whitehead Institute.

degree of MD (medical doctor), Ph. D. in Medical Engineering and Medical Physics (MEMP) is offered, the latter title clearly showing the interdisciplinary nature of the program. In 1982, MIT also founded the Whitehead Institute for Biomedical Research "to identify and support the finest young minds in science". "Each year, Whitehead provides advanced scientific training to more than two hundred students, postdoctoral fellows, physicians, and visiting scientists from around the world." Its Whitehead/MIT Center for Genome Research played an important role in the International Human Genome Project.

Similarly, at the University of California at Berkeley and Stanford University, the reorganization of university organizations to accommodate the progress of molecular biology and other life science disciplines began to be discussed around 1980 and was completed by 1989[8].

We will investigate if similar developments and reorganizations of life science educational programs occurred in Japan. There are three types of universities in Japan – national universities (founded by the central government and incorporated in 2004 as discussed above), municipal universities (founded by local governments, several of which were incorporated in recent years), and private universities. As shown in Table 1, there were about seven hundred universities in 2003 and, in terms of the number of universities, private universities dominated, accounting for three quarters, whereas national universities accounted for only 14 percent. However, national universities accounted for 39 percent of full-time faculty members and 61 percent of graduate students. Apparently, national universities had a higher faculty-student ratio and were geared towards graduate education. Panel B of the same table shows the number of degree earners by fields and by the level of education. Humanities and social sciences together accounted for 57 percent of bachelors. In doctors, by contrast, the top three were health, engineering and science (namely, natural sciences). The statistics does not decompose these

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[8] Jong (2008) made a comparative study of the reorganization of these two universities and argued that the differences between them resulted because Berkeley is a state university whereas Stanford is a private one, Berkeley has no medical school whereas Stanford has one, and Stanford is closer to the Silicon Valley.

numbers into national vs. municipal vs. private universities; however, the two panels together imply that the majority of the faculty members in private universities were in humanities and social sciences, whereas the majority of faculty members in health, engineering, and natural sciences belonged to national universities. This fact should suggest that, even though our analyses below of UI joint research projects in biotechnology will be confined to those in national universities, it is safe to assume that the results apply to the majority of such UI joint research in Japan. Furthermore, except for a few exceptions (most notably Keio and Waseda), nearly all the internationally known universities (e.g., Tokyo, Kyoto, Osaka, and Tokyo Institute of Technology) are national.

We studied organizational changes of Japanese universities using *Zenkoku Daigaku Ichiran* (List of Universities in the Nation) published by Bunkyo Kyokai. It lists the changes in educational and research organizations of all the Japanese universities and, from this source, we picked up the establishment of four types of new educational programs -- “undergraduate schools” (or simply “schools”), “departments” within undergraduate schools, “graduate schools”, and “graduate departments” within graduate schools -- that are related to life sciences and biotechnology. In Japanese, these four programs are, respectively, *gakubu*, *gakka*, *kenkyuka*, and *senko*. Their English translation can differ across universities. In the University of Tokyo, for instance, there is ‘Seibutsu Gakka’ (Department of Biological Sciences) within ‘Rigakubu’ (School of Science or, according to Tokyo’s terminology, Faculty of Science) for undergraduate education and, for graduate education, there is ‘Seibutsu Kagaku Senko’ (Graduate Department of Biological Sciences) within ‘Rigaku Kenkyuka’ (Graduate School of Science).

Basically, we included all such programs that contain ‘life’ or ‘bio’ in their name, such as bioscience, biotechnology, biochemistry, bioinformatics, bioengineering, and life science. Needless to say, the title of a program alone need not prove that it in fact teaches and makes research in the field of life sciences or biotechnology in the modern sense. A bioscience department, for instance, may only teach traditional biological subjects, such as plant taxonomy (without denying that even such subjects have been radically transformed in the past few decades), or it may also teach new ones. Or, the change in name may be superficial so that the supposedly new department is no more than a renamed old department. We often consulted the websites of the departments in question to determine if the changes are real and the new departments are in fact related to life sciences and biotechnology, to find that such ambiguous cases are actually rather rare. Still, by no means do we deny that the results to be shown are subject to errors. This difficulty is even more pronounced if one starts thinking about possible long-run consequences. Suppose, for instance, that a university opened a new school (say, School of Life Sciences) but, except for just a few new hires, all the faculty members came from an existing organization (say, Department of Biology within the School of Sciences). It is perhaps unlikely that the content of teaching is radically changed with the opening of the new school; still, we expect that it will gradually hire people in newer fields to replace those retiring and, in the long run, it will transform to a department deserving the new title. With such an expectation, we basically listed up all the new departments and schools with relevant names.

Figure 2 (for public universities, that is, national and municipal universities) and Figure 3 (for private universities) show the number of establishments of such educational programs since 1955. Apparently, such establishments became common after 1985. Before then, there were at most two establishments per year while, since 1985 and particularly during the 1990s, it was common that more than ten establishments were made. This tendency applies to both public and private universities. Between these two types of universities, public universities were more active in establishing these programs. Together with the fact shown in Table 1 that the number of private universities is more than five times that of public universities, it is obvious that, while many public universities started new programs to teach bio-related subjects, only a very small percentage of private universities did so. A large part of the establishments were made at the department level (both at the undergraduate and graduate levels) than at the school level, obviously because it is more costly and politically demanding to start new schools.

It is difficult to compare this finding to that in the US mainly because, to our knowledge, no comparative study is available and we only know sporadic cases, such as those at MIT, Berkeley, and Stanford mentioned above. In that many Japanese universities started new departments during the 1980s, and that there were also cases, if exceptional ones, in which establishments occurred during the 1970s, it appears difficult to assert if Japan significantly lagged behind the US in this regard[9]. Still there are arguments suggesting that the lag is serious in Japan. We will come back to this topic in the concluding section.

5. Data, Hypotheses, and Variables

As mentioned earlier, UI collaborations can take a variety of forms, such as joint research based on contracts, commissioned research (in which industries commission research to university laboratories), licensing of university patents, donation of research funds by industries, consulting, and faculty members acting as directors or technical advisors in companies. Some are based on formal contracts between the university and the firm(s) while others are informal, for instance, made by faculty members without reporting to their universities. Consequently, it is hard to capture the entire collaborative activities.

In this study we confine our analysis to joint research contracts between national universities and companies. All the national universities were required to report these contracts to the Ministry of Education, Culture, Sports, Science and Technology (MEXT). MEXT's National Institute of Science and Technology Policy (NISTEP) made a study of these reports to analyze the trend and distribution of UI joint research activities (NISTEP, 2003, 2005). With permission of NISTEP,

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[9] Earlier, Yamada and his associates (Hayashi and Yamada, 1975, and Yamada and Tsukahara, 1986) studied the trend of the number of researchers, the amount of research funds, and the number of papers and presentations, as well as the establishment of new departments, in high-polymer chemistry and other new scientific fields, and concluded that the establishment of new departments in Japan significantly lagged behind the international research trend. Unfortunately, it is more difficult to do a similar analysis on life sciences and biotechnology because these correspond to broader fields and developed more continuously after the preceding studies in genetics and biology. Mendel's law, for instance, became known at the beginning of the 20th century.

we will use this data re-compiled at university levels[10].

We are not entirely happy with this focus on joint research contracts only; however, for two reasons, the results should apply reasonably well to UI collaborations in general. The first is that important collaborations tend to occur through joint research contracts. In our interviews, a number of company research officers confirmed this fact by saying that, to clarify the rights and responsibility of each party, they prefer joint research contracts if the projects are important or if they are expected to lead to patentable inventions. Second, with the policy changes discussed in Section 3, universities have become more eager to conclude research contracts. Many universities now have TLOs and liaison officers who help faculty members sign and carry out contracts. These arrangements reduced transaction costs for the contracts and some companies indicated that, whereas they used to simply donate research funds in order to avoid bureaucratic hassles and contract costs, they now conclude research contracts with faculty members.

The required report by universities to MEXT showed the school (which is defined in the sense explained in the previous section and is a more coarse classification than departments) involved in the contract and the industry the firm belonged. During 1995-2000, MEXT also asked to report if the contract is related to one of eight fields – biotechnology, material, energy, software, electronics, machinery development, civil engineering, and construction – or none of these. Using this information, we only consider joint research contracts in the field of biotechnology. The trend of these contracts is summarized in Table 2. Apparently, the number of national universities with these contracts increased during the period, particularly after 1998, the year the TLO Act started. The number of contracts per university also increased from 2.1 in 1995 to 7.2 in 2000.

Let us now investigate if the establishment of new educational programs (schools, departments, graduate schools, or graduate departments) on life sciences and biotechnology led to more active joint research contracts in biotechnology. From

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[10] The authors wish to thank S. Kobayashi, A. Nagata, K. Hasegawa, and other former and present members of NISTEP's Second Research Group for their help.

the discussion in Section 2, we can derive two hypotheses. The first concerns the likelihood that a university undertakes such a contract.

> *Hypothesis 1-1*: A university with at least one educational program on life science or biotechnology is more likely to undertake one or more joint research contracts with companies.

That is, with a good probability, there is a firm located between $\overline{\ell}^{1}_{j-}$ and $\overline{\ell}^{1}_{j+}$ in Figure 1 (given $C = C^1$).

However, there may be a lag in this effect because it may take some years before the new school, etc., becomes fully staffed and active in research and the activity of the new school becomes known to industries[11]. That is, V_j (or, more precisely, firms' perception of V_j) may increase over time and, hence, we have the following hypothesis as a variant of Hypothesis 1-1.

> *Hypothesis 1-2*: A university that established its first educational program on life science or biotechnology earlier is more likely to undertake one or more joint research contracts with companies.

The second group of hypotheses concerns the number of joint research contracts.

> *Hypothesis 2-1*: A university with at least one educational program on life science or biotechnology will have a larger number of joint research contracts with companies.

That is, there will be more firms located between $\overline{\ell}^{1}_{j-}$ and $\overline{\ell}^{1}_{j+}$ in Figure 1.

And, similarly to Hypothesis 1-2, we have

> *Hypothesis 2-2*: A university that established the first educational program on life science or biotechnology earlier will have a larger number of joint research contracts with companies.

We will test these hypotheses with regressions using a panel of 95 national

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[11] Usually, establishment of a new educational program occurs on the 1st of April when a new academic year starts in Japan. Joint research contracts may be concluded at any time of the year but, usually, a few months after April. Hence, even if the start of the program and the contract take place in the same academic year, a few months' delay is common.

universities over six years (1995-2000). The dependent variable to test Hypotheses 1-1 and 1-2 is *COLLABO*, a dummy variable that equals one if and only if the university had at least one joint research contract with firms or industries in biotechnology (subscripts for university (*j*) and for year (*t*) are suppressed; for exact definitions, see Table 3). The dependent variable to test Hypotheses 2-1 and 2-2 is *N_COLLABO*, the number of joint research contracts by the university with firms or industries in the field of biotechnology.

The independent variable to test Hypotheses 1-1 and 2-1 is *LIFE*, a dummy variable that equals one if and only if the university had established at least one educational program in the field of life sciences or biotechnology. The variable to test Hypotheses 1-2 and 2-2 is *LIFE_AGE*, the number of years since the university established its first educational program in the field of life sciences or biotechnology. In addition, to test if the effect of age is linear, we used a group of dummy variables. *LIFE_0-4Y* equals one if and only if the university established its first educational program in the field of life sciences or biotechnology between this year and four years ago. Similarly, we define *LIFE_5-9Y*, *LIFE_10-14Y*, and *LIFE_15Y*, the last indicating that the new program started 15 years ago or earlier.

In addition, we have a number of control variables that may affect the probability and intensity of the university's joint research contracts. Some of these are university-specific, such as the age of the university (*UNIV_AGE*), its size (*UNIV_SIZE*), a dummy variable (*COMPRE*) indicating if the university has both humanistic schools (including humanities and social sciences) and scientific schools (including natural sciences, engineering, agriculture, medical, and pharmaceutical), and a dummy variable (*SCIENCE*) indicating if the university has scientific schools only[12].

Another variable that affects the likelihood or the number of UI joint research is the

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[12] These two dummy variables are both zero if the university has only humanistic schools. Since these universities may be presumed not to perform joint research on biotechnology, we re-estimated the equations excluding these universities (and excluding the *SCIENCE* variable). The results are basically the same and not reported (see Kato and Odagiri, 2010).

quality of schools (or departments), because this quality determines V_j in Figure 1 and hence the number of firms within $\overline{\ell}^1_{j-}$ and $\overline{\ell}^1_{j+}$. A common measure of school quality is the number of papers by the faculty members (preferably weighted by the frequency of being cited by subsequent papers or patents). However, there is a causality issue. That is, such papers will come out only after the school is established; hence, the number of papers must be larger for universities with life-science schools (or departments) and for universities with a longer history of such schools, causing correlation with our main dependent variables, *LIFE* and *LIFE_AGE*.

We therefore prefer a variable indicating the intrinsic quality of the university whether it has a life-science school or not. In Japan (and perhaps in many other countries), such quality is likely best approximated by the difficulty of being admitted. All national universities select students based on two types of entrance examinations, one being a nationwide examination and the other being an examination carried out by individual universities (and in many cases by individual schools within universities). Based on the estimated scores of students accepted for entrance, several preparatory schools publish indices of the difficulties of universities. This index, denoted by *SCORE,* is calculated as normalized standard deviation; that is, it equals 50 if the minimum examination score needed for admission to the school equals the mean of such scores over all schools and all universities (whether national, municipal, and private) and 60 if it is higher than the mean by one standard deviation. It varies across universities (with the University of Tokyo gaining the highest score) and across schools (with medical schools gaining the highest score in most universities). The score we used is that for the school of natural sciences[13]. Since we want it to be unaffected by the start of new schools, it was measured prior to the sample period, that is, in 1994.

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[13] In case the university does not have a school of natural sciences, we estimated it by extrapolation, that is, by multiplying the scores of schools present in the university by the mean inter-school ratios of all universities. The score we used is that published by Fukutake Shoten, one of the major preparatory schools in Japan. A few other preparatory schools also publish the scores and the correlation among them is sufficiently high.

SCORE and *UNIV_SIZE* turned out to be highly correlated (r =0.424): for instance, the University of Tokyo is the largest and the most difficult to be admitted. Therefore, we will use these two variables alternatively. Table 3 gives the definition of each variable and the basic statistics. In addition, we used year dummies (*Y1996*, etc.) to control for time effects.

6. Estimation Results

The estimated coefficients and computed marginal effects (dF/dx) are shown in Tables 4 and 5. For estimation, we used probit models to test Hypotheses 1-1 and 1-2 and, to test Hypotheses 2-1 and 2-2, we used negative binomial models since the dependent variable is a count data[14].

Table 4 shows that both *LIFE* and *LIFE_AGE* have significantly positive coefficients, supporting Hypotheses 1-1 and 1-2. A university with relevant educational programs is more likely to participate in joint research on biotechnology with industries and this probability increases with years after the establishment of such programs. Equations (1-2) and (1-5) confirm that the probability increases over the years, although the increase becomes insignificant after ten years of the establishment, mainly because most universities begin joint research within ten years of school establishment.

Table 5 supports Hypotheses 2-1 and 2-2, that is, a university with relevant programs tends to have a larger number of joint research contracts and the older the program the more contracts the university tends to have. Equations (2-2) and (2-5) suggest the presence of age effect because the estimated marginal effects are larger with larger year lags. Together with equations (1-2) and (1-5), it is suggested that, even if the probability of having at least one contract stabilizes after ten years, the number of contracts continues to rise, indicating the long-lasting presence of experience effects caused by, for example, accumulated research expertise, intensified network

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[14] All the estimations were also made with random effects. As shown in Appendix Tables A1 and A2, the results are similar to those in Tables 4 and 5 and the following discussions basically apply with or without random effects.

between faculty members and industries, and learning-by-doing by the administrative staff on UI liaison and contracting.

Both *UNIV_SIZE* and *SCORE* have significant and positive coefficients with similar explanatory power. Thus, there may be a university-wide scale effect or a quality effect. *UNIV_AGE* rarely have significant coefficients, suggesting the lack of a university-wide age effect. *COMPRE* and *SCIENCE* have positive and significant coefficients in both probit and negative binomial models. Interestingly, the computed marginal effects of *SCIENCE* and *COMPRE* are not significantly different in the probit model whereas *SCIENCE* always has larger effects than *COMPRE* in the negative binomial model, implying that universities with scientific schools only (e.g., Tokyo Institute of Technology and Tokyo Medical and Dental University) tend to be more active in joint research than comprehensive universities (e.g., the University of Tokyo), even though, *ceteris paribus*, the probability of occurrence of joint research hardly differs between the two types of universities. Put differently, the economies of scope from having humanistic schools (including social science schools) in the same university appears unimportant.

Finally, the coefficients of year dummies (with year 1995 as the benchmark) indicate that joint research has become more active over the six-year period. In the probit model, the coefficients are significant for 1999 (in equation 1-1 only) and 2000. In the negative binomial model, they are significant for 1998 (except in equation 2-3 and 2-6), 1999, and 2000. The estimated marginal effects increase with years and, particularly in the negative binomial model, the increase from 1998 to 1999 and then to 2000 is impressive.

These results suggest that, in the years 1999 and 2000, more universities started to have UI joint research and, more evidently, the number of joint research contracts increased significantly. These findings are consistent with the general trend we observed in Table 2 and suggest the contributions of two policy initiatives, that is, the enactment of the TLO Act in 1998 and the Japanese Bayh-Dole Act in 1999. We are inferring the effects of these policies only with the year effects and have not directly tested the influences of the policies; therefore, this conclusion remains as tentative. Still, it is consistent with the view that these laws encouraged and assisted both universities and industries to make joint research contracts.

7. Conclusions and Implications

This paper studied the development of university educational programs in the fields of life sciences and biotechnology. Our data on the establishment of new such programs (schools and departments, both at undergraduate and graduate levels) in Japan indicated that the majority of universities started these programs since 1985 and particularly during the 1990s. We then looked at the data on the number of joint research contracts that national universities concluded with industries in relation to biotechnology. The number of contracts per university was found to have increased rapidly.

Our university-year panel regression results indicate that these two events are related. A university is more likely to enter into one or more joint research contracts and tend to enter into more such contracts if the university has already have an educational program in the field of life sciences and biotechnology. And this probability and tendency are stronger when the university has a longer history of these educational programs. Our results also supported the hypothesis that the two major policy initiatives, the TLO Act in 1998 and the Japanese Bayh-Dole Act in 1999, played the intended role of fostering university-industry collaborations.

We may draw three useful implications from these results. First, at least in the field of life sciences and biotechnology, it was confirmed that the presence of educational institutions in related fields is a prerequisite for UI collaborations. Often, establishing new programs in response to new scientific development tends to delay, owing to budgetary constraints and intra-university conflicts, and policy efforts are needed to avoid such delay. The US universities have been said to retain greater autonomy and be more responsive to changing socio-economic demands (Mowery and Sampat, 2005). In comparison, Japanese universities appear less responsive partly because most major universities are national and used to depend on state budgets and government regulations and guidance, and partly because intra-university departmental autonomy has been emphasize, making it more difficult to make inter-departmental adjustments and collaborations. Our study inquired into the development of new programs only for Japan. Comparative studies on other countries, with national differences in university systems into considerations, are needed.

Second, it may take several years before the establishment of a new educational program starts to contribute to UI joint research. Ostensibly such time lag is inevitable because it takes several years before the program runs in full capacity, the graduate students become knowledgeable and capable enough to contribute to the laboratories as research assistants, the faculty members establish a network with companies, and the university administration accumulates sufficient capability to establish liaison with companies and handle research contracts. We believe the last factor to be particularly important. Even in the US, Mowery et al. (2004) argued that, the passage of Bayh-Dole Act of 1980 prompted inexperienced universities to apply for patents of little value and it took a number of years before the administrators of these universities accumulated sufficient capabilities to winnow out faculty inventions of little value (also see footnote 4 above). The administrators of Japanese universities may have been even more inexperienced because national universities depended on the government fund and were subject to heavy regulations. Most inventions used to be given to industries, which then patented them and, as a sort of compensation, donated research funds to the inventing faculty members. Since the enactment of the Japanese Bayh-Dole Act and the National University Corporation Law, many universities set up TLOs and other liaison offices and some hired specialists from outside. The number of patenting and licensing, as well as joint research contracts, has been increasing. Still, even more efforts will be needed to foster the accumulation of experience and skills for these activities.

Third, the TLO Act, which promoted the establishment of technology licensing offices, and the Japanese Bayh-Dole Act, which allowed universities to retain rights for inventions made from government-supported research projects, seem to have had the expected effects. To inquire fully into the effects, we need to know also about patenting, licensing, and other activities. Also, we wish to extend the period of study to more recent years to know the impact of the incorporation of national universities in 2004. Due to data limitation, we need to postpone these studies for future task. Still, the present study indicated the importance of policy initiatives in fostering UI collaborations. Particularly in such science-based fields as biotechnology and pharmaceuticals, the presence of universities with educational programs and research facilities in related fields is essential as well as the presence of policies and institutions that support technology transfer from universities to industries and joint research between them.

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Figure 1. University-Industry Collaborations in a Spatial Model

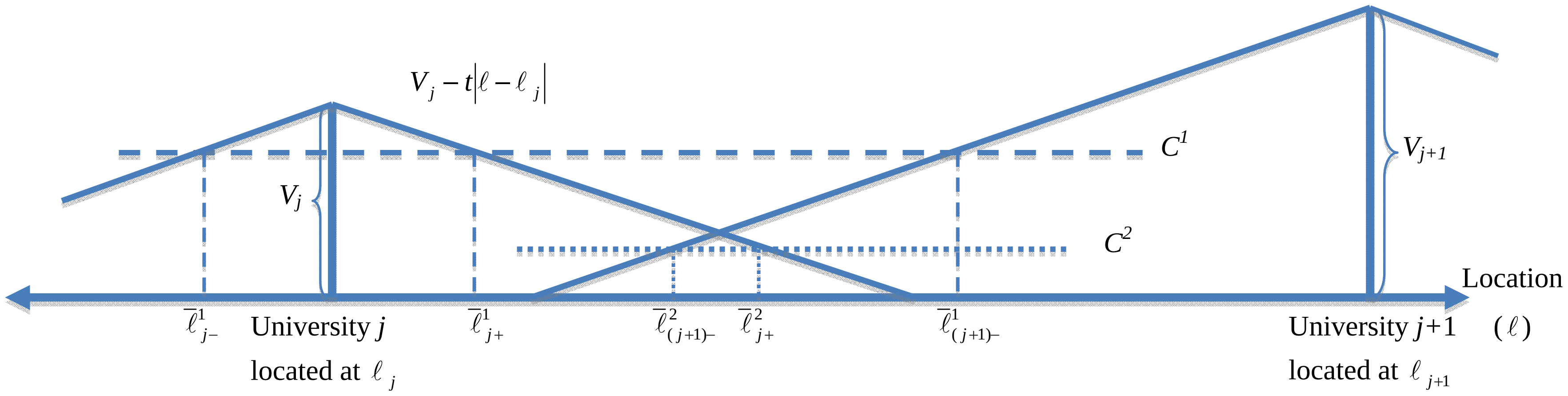

Figure 2. Establishments of New Educational Programs on Life Sciences and Biotechnology: National and Municipal Universities

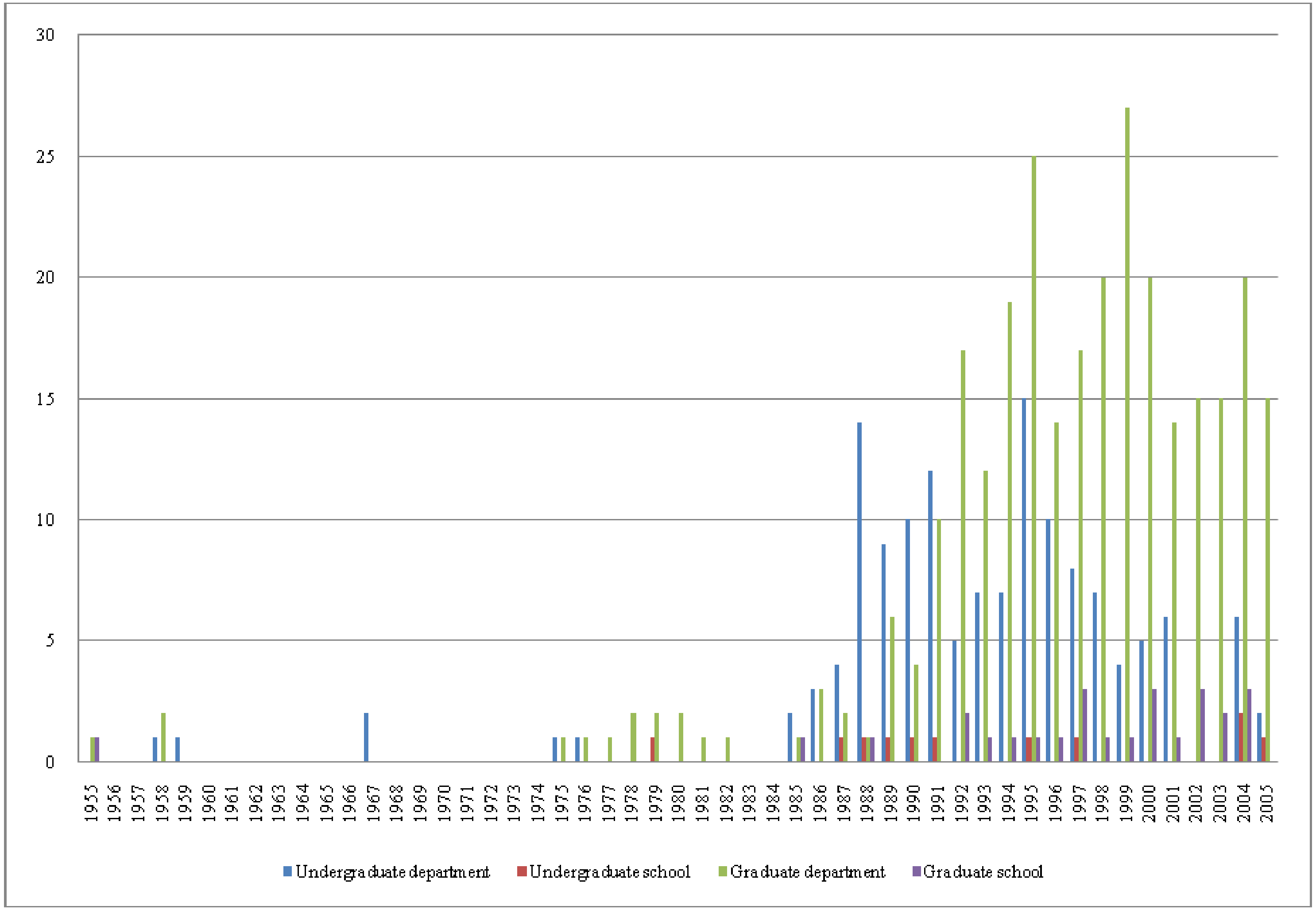

Figure 3. Establishments of New Educational Programs on Life Sciences and Biotechnology: Private Universities

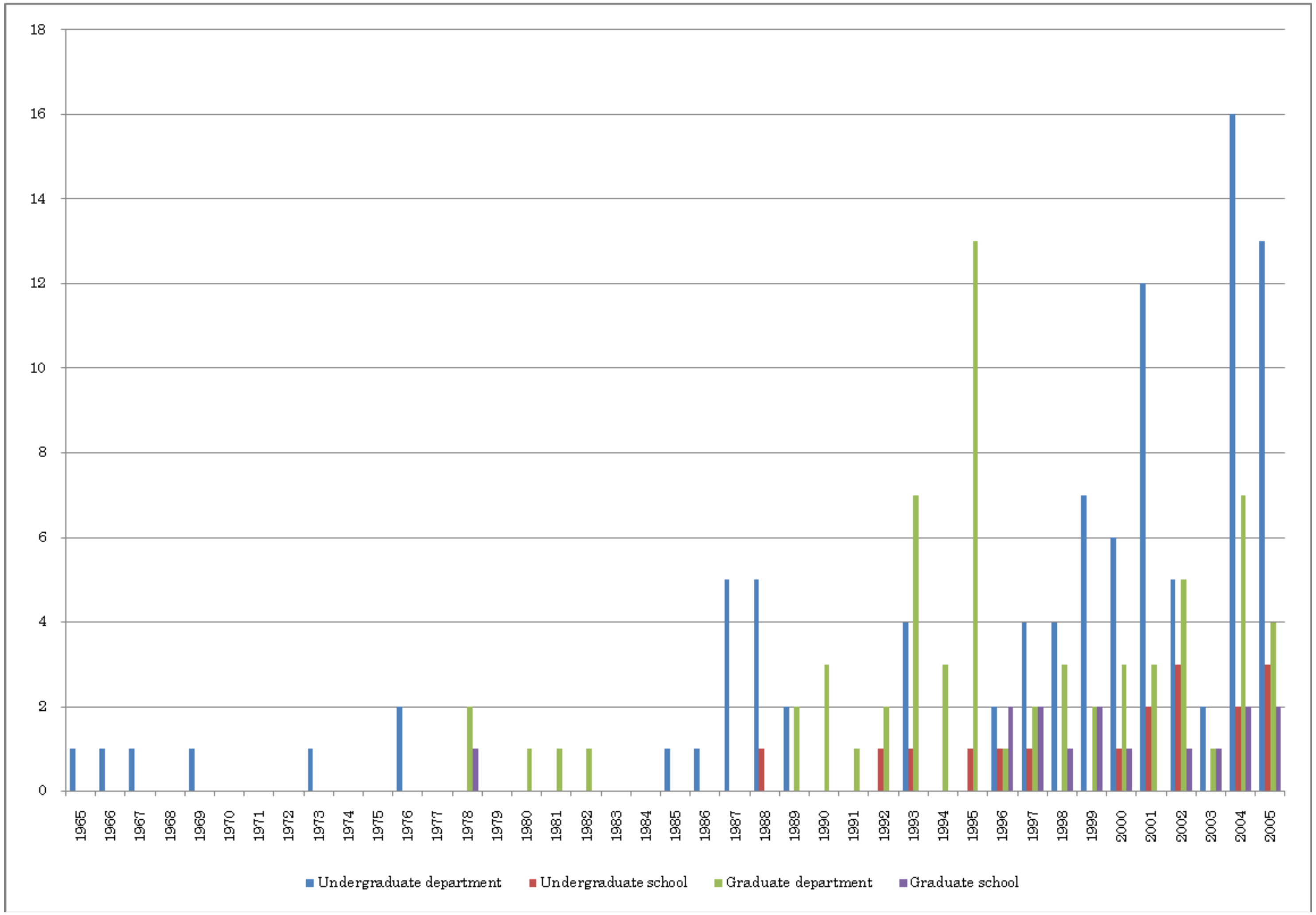

Table 1. Universities in Japan, 2003

(A) By Type of Organizations

	National	(%)	Municipal	(%)	Private	(%)	Total	(%)
Number of universities	100	14.2%	76	10.8%	526	74.9%	702	100.0%
Number of faculty members								
full-timers	60,882	39.0%	10,977	7.0%	84,296	54.0%	156,155	100.0%
part-timers	40,113	25.9%	9,810	6.3%	104,747	67.7%	154,670	100.0%
Number of students								
undergraduates	460,483	18.4%	103,407	4.1%	1,945,484	77.5%	2,509,374	100.0%
graduates	142,184	61.4%	12,796	5.5%	76,509	33.1%	231,489	100.0%

(B) By Fields: Number of Students Finishing the Course

	Undergraduates	(%)	Masters	(%)	Doctors	(%)
Humanities	93,744	17.2%	4,836	7.2%	1,383	9.5%
Social science	215,205	39.5%	9,830	14.6%	1,162	8.0%
Science	19,549	3.6%	5,722	8.5%	1,500	10.3%
Engineering	101,401	18.6%	28,498	42.3%	3,212	22.1%
Agriculture	15,933	2.9%	3,471	5.1%	1,093	7.5%
Health	30,479	5.6%	3,733	5.5%	4,561	31.4%
Mercantile marine	198	0.0%	12	0.0%	―	0.0%
Home economics	10,822	2.0%	444	0.7%	50	0.3%
Education (incl. teacher training)	31,767	5.8%	5,036	7.5%	362	2.5%
Arts	15,222	2.8%	1,431	2.1%	96	0.7%
Others	10,574	1.9%	4,399	6.5%	1,093	7.5%
Total	544,894	100.0%	67,412	100.0%	14,512	100.0%

Table 2. Number of University-Industry Joint Research Contracts in biotechnology: National Universities, 1995-2000

	1995	1996	1997	1998	1999	2000
No. of all universities	95	95	95	95	95	95
No. of universities performing UI joint research	50	51	52	57	60	64
No. of universities newly performing UI joint research	-	7	6	11	7	7
No. of contracts	204	267	274	305	427	684
No. of contracts per university	2.1	2.8	2.9	3.2	4.5	7.2

Note
“Universities newly performing UI joint research” refer to the universities who had no joint research contract in the previous year but had one or more in the current year. Because of the presence of universities having performed joint research in the previous year but having none in the current year, “the number of universities newly performing UI joint research” may exceed the increase in “the number of universities performing UI joint research.”

Table 3. List of Variables and Descriptive Statistics (Number of observations: 570)

Variable Name	Definition	Mean	Standard deviation
<u>Dependent variables</u>			
$COLLABO_{j,t}$	Equals one if and only if university *j* had at least one joint research contract with firms or industries in biotechnology in year *t* (dummy variable)	0.586	0.493
$N\_COLLABO_{j,t}$	The number of joint research contract by university *j* with firms or industries in biotechnology in year *t*	3.675	6.437
<u>Independent variables</u>			
$LIFE_{j,t}$	Equals one if and only if university *j* had established at least one educational program in the field of life sciences or biotechnology by year *t* (dummy variable)	0.514	0.500
$LIFE\_0\text{-}4Y_{j,t}$	Equals one if and only if university *j* established its first educational program in the field of life sciences or biotechnology between year *t*-4 and year *t* (dummy variable)	0.075	0.264
$LIFE\_5\text{-}9Y_{j,t}$	Equals one if and only if university *j* established its first educational program in the field of life sciences or biotechnology between year *t*-9 and year *t*-5 (dummy variable)	0.204	0.403
$LIFE\_10\text{-}14Y_{j,t}$	Equals one if and only if university *j* established its first educational program in the field of life sciences or biotechnology between year *t*-14 and year *t*-10 (dummy variable)	0.126	0.332
$LIFE\_15Y_{j,t}$	Equals one if and only if university *j* established its first educational program in the field of life sciences or biotechnology before or in year *t*-15 (dummy variable)	0.109	0.312
$LIFE\_AGE_{j,t}$	Years since university *j* established its first educational program in the field of life sciences or biotechnology	6.284	8.540
$UNIV\_SIZE_{j,t}$	The size of university *j* as measured by the number of new students admitted in year *t* at schools and departments at undergraduate level (thousands)	1.075	1.815
$SCORE_j$	Index (normalized standard deviation) of the minimum examination score needed for admission to the school of science (undergraduate) in 1994	56.231	5.424
$UNIV\_AGE_{j,t}$	Years since establishment of university *j*	42.879	11.589
$COMPRE_{j,t}$	Equals one if and only if university *j* has both humanistic and scientific schools (dummy variable)	0.505	0.500
$SCIENCE_{j,t}$	Equals one if and only if university *j* has scientific schools only (dummy variable)	0.295	0.456

Table 4. Occurrence of UI Joint Research: Probit model

	Dependent Variable: *COLLABO*											
	(1-1)		(1-2)		(1-3)		(1-4)		(1-5)		(1-6)	
Variable	Coeff.	d*F*/d*x*	Coeff.	d*F*/d*x*	Coeff.	d*F*/d*x*	Coeff.	d*F*/d*x*	Coeff.	d*F*/d*x*	Coeff.	d*F*/d*x*
LIFE	1.197***	0.438					1.367***	0.494				
	(0.167)	(0.055)					(0.165)	(0.051)				
*LIFE*_0-4*Y*			0.999***	0.305					1.007***	0.306		
			(0.234)	(0.051)					(0.237)	(0.051)		
*LIFE*_5-9*Y*			1.256***	0.391					1.461***	0.432		
			(0.211)	(0.048)					(0.216)	(0.044)		
*LIFE*_10-14*Y*			1.367***	0.388					1.550***	0.414		
			(0.268)	(0.047)					(0.263)	(0.040)		
*LIFE*_15*Y*			1.438***	0.392					1.732***	0.428		
			(0.364)	(0.055)					(0.334)	(0.038)		
LIFE_AGE					0.088***	0.033					0.101***	0.038
					(0.016)	(0.006)					(0.015)	(0.005)
UNIV_SIZE	0.508***	0.195	0.432**	0.166	0.308*	0.116						
	(0.149)	(0.057)	(0.169)	(0.065)	(0.161)	(0.060)						
SCORE							0.046***	0.018	0.043***	0.017	0.290*	0.011
							(0.015)	(0.006)	(0.016)	(0.006)	(0.016)	(0.006)
UNIV_AGE	-0.002	-0.001	-0.0001	-0.00004	0.004	0.001	0.005	0.002	0.005	0.002	0.007	0.003
	(0.007)	(0.003)	(0.007)	(0.003)	(0.007)	(0.003)	(0.007)	(0.003)	(0.007)	(0.003)	(0.007)	(0.003)
COMPRE	1.170***	0.428	1.136***	0.416	1.420***	0.497	1.481***	0.527	1.350***	0.484	1.574***	0.540
	(0.257)	(0.087)	(0.263)	(0.089)	(0.247)	(0.079)	(0.244)	(0.075)	(0.250)	(0.080)	(0.237)	(0.073)
SCIENCE	1.676***	0.516	1.647***	0.507	1.674***	0.493	1.612***	0.505	1.585***	0.492	1.616***	0.477
	(0.226)	(0.055)	(0.226)	(0.056)	(0.220)	(0.054)	(0.229)	(0.057)	(0.227)	(0.057)	(0.220)	(0.055)
Y1996	0.027	0.010	0.005	0.002	-0.016	-0.006	0.020	0.008	-0.017	-0.007	-0.025	-0.009
	(0.224)	(0.086)	(0.224)	(0.086)	(0.217)	(0.082)	(0.222)	(0.085)	(0.223)	(0.086)	(0.216)	(0.081)
Y1997	0.045	0.017	0.020	0.007	-0.020	-0.008	0.040	0.015	-0.004	-0.002	-0.038	-0.014
	(0.224)	(0.086)	(0.224)	(0.086)	(0.219)	(0.082)	(0.222)	(0.085)	(0.224)	(0.086)	(0.218)	(0.082)
Y1998	0.265	0.099	0.232	0.087	0.150	0.055	0.237	0.089	0.188	0.071	0.117	0.043
	(0.230)	(0.083)	(0.232)	(0.084)	(0.226)	(0.081)	(0.229)	(0.083)	(0.231)	(0.085)	(0.225)	(0.081)
Y1999	0.406*	0.149	0.357	0.131	0.224	0.081	0.371	0.137	0.308	0.114	0.179	0.065
	(0.230)	(0.079)	(0.234)	(0.081)	(0.228)	(0.080)	(0.229)	(0.080)	(0.234)	(0.082)	(0.226)	(0.080)
Y2000	0.572**	0.203	0.519**	0.185	0.407*	0.143	0.499**	0.181	0.440*	0.159	0.344	0.122
	(0.236)	(0.075)	(0.242)	(0.078)	(0.236)	(0.077)	(0.234)	(0.077)	(0.239)	(0.080)	(0.233)	(0.077)
Constant term	-2.132***		-2.091***		-2.028***		-4.625***		-4.435***		-3.574***	
	(0.359)		(0.360)		(0.352)		(0.921)		(0.977)		(0.955)	
Number of obs.	570		570		570		570		570		570	
Pseudo R^2	0.394		0.396		0.370		0.391		0.397		0.369	
Log likelihood	-234.239		-233.378		-243.635		-235.549		-233.144		-243.911	

Notes: *COLLABO* = *N_COLLABO*=0 in 236 observations (that is, no UI joint research contract was made in 236 university-year combinations). Standard errors are shown in parentheses. The significance level is shown by ***(1%), **(5%), and *(10%).

Table 5. Determinants of the Number of UI Joint Research Contracts: Negative binomial model

	Dependent Variable: *N_COLLABO*											
	(2-1)		(2-2)		(2-3)		(2-4)		(2-5)		(2-6)	
Variable	Coeff.	d*F*/d*x*	Coeff.	d*F*/d*x*	Coeff.	d*F*/d*x*	Coeff.	d*F*/d*x*	Coeff.	d*F*/d*x*	Coeff.	d*F*/d*x*
LIFE	1.473***	2.102					1.596***	2.276				
	(0.156)	(0.295)					(0.152)	(0.301)				
*LIFE*_0-4*Y*			1.214***	2.876					1.158***	2.644		
			(0.213)	(0.836)					(0.212)	(0.784)		
*LIFE*_5-9*Y*			1.446***	3.223					1.575***	3.675		
			(0.173)	(0.647)					(0.169)	(0.697)		
*LIFE*_10-14*Y*			1.557***	4.097					1.690***	4.718		
			(0.189)	(0.922)					(0.183)	(1.001)		
*LIFE*_15*Y*			1.983***	6.722					2.023***	6.959		
			(0.224)	(1.639)					(0.206)	(1.567)		
LIFE_AGE					0.066***	0.093					0.072***	0.103
					(0.009)	(0.015)					(0.009)	(0.015)
UNIV_SIZE	0.709***	0.945	0.495**	0.659	0.319***	0.454						
	(0.086)	(0.137)	(0.107)	(0.151)	(0.111)	(0.161)						
SCORE							0.069***	0.091	0.054***	0.071	0.020*	0.028
							(0.009)	(0.013)	(0.010)	(0.015)	(0.012)	(0.017)
UNIV_AGE	0.0005	0.001	0.007	0.009	0.022	0.032	0.008	0.010	0.011*	0.015	0.026	0.037
	(0.006)	(0.008)	(0.007)	(0.009)	(0.006)	(0.009)	(0.006)	(0.008)	(0.006)	(0.008)	(0.006)	(0.009)
COMPRE	2.270***	3.675	2.305***	3.752	2.958 ***	5.821	2.885***	5.172	2.692***	4.670	3.201***	6.683
	(0.396)	(0.706)	(0.398)	(0.720)	(0.386)	(0.930)	(0.391)	(0.853)	(0.391)	(0.798)	(0.385)	(1.027)
SCIENCE	3.221***	12.410	3.177***	12.000	3.460***	15.799	3.141***	11.528	3.098***	11.227	3.386***	15.049
	(0.384)	(2.858)	(0.383)	(2.760)	(0.382)	(3.535)	(0.387)	(2.680)	(0.383)	(2.592)	(0.381)	(3.372)
Y1996	0.236	0.341	0.198	0.282	0.110	0.162	0.225	0.320	0.173	0.243	0.103	0.152
	(0.184)	(0.289)	(0.182)	(0.278)	(0.185)	(0.283)	(0.181)	(0.278)	(0.179)	(0.267)	(0.185)	(0.284)
Y1997	0.309*	0.458	0.255	0.371	0.101	0.149	0.293	0.425	0.219	0.312	0.087	0.129
	(0.184)	(0.305)	(0.183)	(0.292)	(0.185)	(0.282)	(0.182)	(0.293)	(0.181)	(0.278)	(0.186)	(0.282)
Y1998	0.416**	0.641	0.354*	0.534	0.162	0.243	0.387**	0.582	0.304*	0.446	0.139	0.209
	(0.183)	(0.327)	(0.184)	(0.314)	(0.184)	(0.292)	(0.180)	(0.312)	(0.181)	(0.296)	(0.184)	(0.290)
Y1999	0.828***	1.496	0.725***	1.257	0.446**	0.742	0.770***	1.341	0.649***	1.085	0.404**	0.665
	(0.181)	(0.447)	(0.186)	(0.422)	(0.182)	(0.357)	(0.179)	(0.416)	(0.183)	(0.388)	(0.182)	(0.348)
Y2000	1.271***	2.764	1.135***	2.327	0.811***	1.551	1.163***	2.381	1.023***	1.986	0.747***	1.401
	(0.178)	(0.625)	(0.186)	(0.581)	(0.181)	(0.470)	(0.175)	(0.560)	(0.181)	(0.517)	(0.179)	(0.446)
Constant term	-3.860***		-3.883***		-4.147***		-7.603***		-6.750***		-5.174***	
	(0.465)		(0.468)		(0.465)		(0.692)		(0.742)		(0.832)	
Number of obs.	570		570		570		570		570		570	
Pseudo R^2	0.175		0.179		0.163		0.175		0.181		0.161	
Log likelihood	-1066.246		-1060.871		-1080.977		-1065.813		-1058.817		-1083.728	

Notes: See the notes to Table 4.

Appendix A. Additional estimations

Table A1. Occurrence of UI Joint Research: Random-effects probit model

	Dependent Variable: *COLLABO*					
	(A1-1)	(A1-2)	(A1-3)	(A1-4)	(A1-5)	(A1-6)
Variable	Coeff.	Coeff.	Coeff.	Coeff.	Coeff.	Coeff.
LIFE	1.673***			1.946***		
	(0.417)			(0.412)		
*LIFE*_0-4*Y*		1.473***			1.590***	
		(0.476)			(0.479)	
*LIFE*_5-9*Y*		1.805***			2.060***	
		(0.492)			(0.489)	
*LIFE*_10-14*Y*		1.901***			2.179***	
		(0.597)			(0.583)	
*LIFE*_15*Y*		2.234**			2.814***	
		(0.928)			(0.861)	
LIFE_AGE			0.113***			0.138
			(0.041)			(0.039)
UNIV_SIZE	1.033**	0.891*	0.856*			
	(0.429)	(0.464)	(0.494)			
SCORE				0.072*	0.062	0.041
				(0.039)	(0.042)	(0.046)
UNIV_AGE	-0.001	0.001	0.005	0.011	0.011	0.016
	(0.019)	(0.019)	(0.021)	(0.018)	(0.018)	(0.019)
COMPRE	2.161***	2.093***	2.692***	2.771***	2.542***	3.105***
	(0.716)	(0.730)	(0.754)	(0.691)	(0.696)	(0.732)
SCIENCE	3.010***	2.954***	3.188***	2.794***	2.747***	2.972***
	(0.665)	(0.661)	(0.707)	(0.639)	(0.633)	(0.671)
Y1996	0.045	0.016	0.007	0.039	-0.002	-0.007
	(0.287)	(0.288)	(0.283)	(0.283)	(0.286)	(0.279)
Y1997	0.104	0.066	0.034	0.088	0.035	-0.008
	(0.289)	(0.292)	(0.288)	(0.286)	(0.289)	(0.284)
Y1998	0.457	0.412	0.329	0.414	0.356	0.253
	(0.297)	(0.301)	(0.301)	(0.294)	(0.298)	(0.294)
Y1999	0.721**	0.662**	0.543*	0.638**	0.570*	0.426
	(0.308)	(0.318)	(0.316)	(0.303)	(0.311)	(0.305)
Y2000	0.965***	0.898***	0.840**	0.837***	0.767**	0.693**
	(0.322)	(0.331)	(0.336)	(0.312)	(0.320)	(0.320)
Constant term	-3.783***	-3.716***	-3.823***	-7.603***	-6.994***	-5.929**
	(0.951)	(0.950)	(1.013)	(2.378)	(2.501)	(2.680)
Number of obs.	570	570	570	570	570	570
Log likelihood	-194.311	-193.861	-198.119	-196.038	-194.821	-199.410

Notes: *COLLABO* = *N_COLLABO*=0 in 236 observations (that is, no UI joint research contract was made in 236 university-year combinations). Standard errors are shown in parentheses. The significance level is shown by ***(1%), **(5%), and *(10%).

Table A2. Determinants of the Number of UI Joint Research Contracts: Random-effects negative binomial model

	Dependent Variable: *N_COLLABO*					
	(A2-1)	(A2-2)	(A2-3)	(A2-4)	(A2-5)	(A2-6)
Variable	Coeff.	Coeff.	Coeff.	Coeff.	Coeff.	Coeff.
LIFE	1.262***			1.333***		
	(0.314)			(0.312)		
*LIFE*_0-4*Y*		1.242***			1.283***	
		(0.328)			(0.327)	
*LIFE*_5-9*Y*		1.223***			1.283***	
		(0.318)			(0.316)	
*LIFE*_10-14*Y*		1.228***			1.310***	
		(0.330)			(0.325)	
*LIFE*_15*Y*		1.657***			1.694***	
		(0.393)			(0.381)	
LIFE_AGE			0.052***			0.052***
			(0.018)			(0.019)
UNIV_SIZE	0.605***	0.459**	0.357			
	(0.185)	(0.204)	(0.222)			
SCORE				0.068***	0.054**	0.036
				(0.020)	(0.021)	(0.025)
UNIV_AGE	0.004	0.007	0.022*	0.011	0.012	0.027**
	(0.014)	(0.014)	(0.013)	(0.014)	(0.014)	(0.013)
COMPRE	2.469***	2.545***	2.962***	2.964***	2.908***	3.304***
	(0.531)	(0.533)	(0.513)	(0.516)	(0.516)	(0.510)
SCIENCE	3.085***	3.055***	3.250***	2.973***	2.958***	3.175***
	(0.491)	(0.493)	(0.495)	(0.500)	(0.497)	(0.496)
Y1996	0.259**	0.258**	0.213**	0.249**	0.247**	0.206*
	(0.107)	(0.107)	(0.108)	(0.106)	(0.106)	(0.108)
Y1997	0.263**	0.256**	0.152	0.233**	0.230**	0.135
	(0.111)	(0.111)	(0.116)	(0.110)	(0.110)	(0.114
Y1998	0.400***	0.382***	0.209*	0.341***	0.331***	0.176
	(0.112)	(0.116)	(0.125)	(0.110)	(0.112)	(0.120)
Y1999	0.760***	0.733***	0.499***	0.663***	0.651***	0.445***
	(0.113)	(0.121)	(0.137)	(0.109)	(0.115)	(0.127)
Y2000	1.248***	1.201***	0.923***	1.133***	1.106***	0.858***
	(0.118)	(0.131)	(0.152)	(0.111)	(0.119)	(0.137)
Constant term	-2.039**	-2.043**	-2.370***	-5.764***	-4.999***	-4.325***
	(0.792)	(0.801)	(0.788)	(1.399)	(1.469)	(1.644)
Number of obs.	570	570	570	570	570	570
Log likelihood	-915.683	-913.982	-918.731	-914.554	-913.147	-918.973

Note: See the notes to Table A1.